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PHOTOVOLTAIC DEPLOYMENT : FROM SUBSIDIES TO A MARKET-DRIVEN GROWTH : A PANEL ECONOMETRICS APPROACH

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Photovoltaic deployment: from subsidies to a market-driven growth: A panel econometrics approach*.

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ABSTRACT

Many reviews were published these last years about the photovoltaic development. It also reflects the importance of green energy and business at the heart of today's preoccupations. According to the Global Market Outlook of May 2012, the global cumulative installed capacity switched from 40GW to 70GW between 2010 and 2011. By the past, the PV growth was geographically concentrated in a small fraction of countries: more than 70% in Germany, Spain, Italy and Bulgaria for Europe, United States and Japan for the Rest of the World. Without deploying in their country, China firms have enacted an overwhelming competition to the former majors. In 2011, more than six international firms have bankrupted such as Q-Cells, the German leader producer. The main purpose of this paper is to make up an econometric model close to the market evolution. This paper differs from those earlier studies in that we identify a number of issues to explain the worldwide pricing. We use a panel estimation approach to identify variables, which drive the photovoltaic production and installation. This analysis represents an opportunity to develop PV in developing countries (India and Africa for examples) where there is a real lack of electricity.

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INTRODUCTION

Solar irradiation provides the largest renewable energy potential. Hence, the solar photovoltaic is considered as the leading solution to substitute electricity production from nuclear plants and fossil sources. Photovoltaic is considered as the wunderkind between the different renewable energy solutions because of the important amounts invested in the sector since ten years. The cost of photovoltaic has declined by a factor nearly 100 since the 1950s[1].

According to the Global Market Outlook of May 2012, the global cumulative installed capacity switched from 40GW to 70GW between 2010 and 2011. It represents a net growth of 75%. By the past, the PV growth was geographically concentrated in a small fraction of countries: more than 70% in Germany, Spain, Italy and Bulgaria for Europe, United States and Japan for the Rest of the World. In 2011, Italy is become the top PV Market with 9.3GW[2] connected to the grid followed by Germany with 7.5GW[3]. For the first time, on May 22, 2012[4], Germany succeeded to produce the half of it electricity with all renewable energy plants.

This fattest growth was explained by extents like support policies such as tax rebate in France, feed-in-tariffs in Europe and Japan, or Renewable Portfolio Standards in the USA. On the other hand, module and base on system cost reduction enables to reach levelized cost of energy (LCOE) ranges from 16cts-35cts€/Kwh[5] produced depending on the weather, the location and the size of the installation: PV electricity is reaching the grid parity. This was possible with industry concentration, market power and the elasticity of demand and prices.[6]

Meanwhile, Mathieu Glachant, in his paper "Innovation and International technology transfer" highlighted the role of Chinese producers who acquire technologies and skills necessary to produce photovoltaic modules, which have triggered the cost reduction of the worldwide PV during the five last years. Indeed, raw material reserves, the purchasing of equipments and the recruitment of high skilled executives from the Chinese diaspora have enabled to set up China firms. Without deploying in their country, China firms have enacted an overwhelming competition to the former majors. In 2011, more than six international firms have bankrupted such as Q-Cells, the German leader producer. Growth in expected future demand and the ability to manage investment risk were the main drivers of the PV sector. This analysis of the cost reduction represents an opportunity to develop PV in developing countries (India and Africa for example) where there is a real lack of electricity.

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[1] Wolf, 1974.
[2] EPIA Global Market Until 2016, p13
[3] EPIA Global Market Until 2016, p13
[4] http://www.zonebourse.com/actualite-bourse/Production-record-d-electricite-d-origine-solaire-en-Allemagne--14345438/
[5] Solar Buzz Quarterly 2011
[6] Beyond the learning curve, Nemet,p28

To summarize, the trend of the PV industry and the worldwide installed capacity do not fit with the previous one. Guidolin and Mortarino in 2010 apply the Bass Model to the PV sector, until Gregory Nemet in 2005 analysed factors as learning curve which influence the cost reduction and the fast deployment. Nowadays, these previous literatures are inappropriate to observe and to analyze the market drivers because it will be more and more difficult to take into account the FIT evolution (Germany declared that they will stop all incentive policies if they reach 52GW installed) or the production structure due to the Chinese companies dumping.

The main purpose of this paper is to make up an econometric model close to the market evolution. This paper differs from those earlier studies in that we identify a number of issues to explain the worldwide pricing. Based on Creti and Joaug "Let the Sun Shine" paper, we propose a panel estimation which compares the production structure of the producing countries. This upstream approach enables us to rank the weight of each independent variable, which affects the production. As so long as there is a correlation between the production level and the installed capacity, we will be able to forecast the installed capacity for the years to come and to identify the new potential market for the PV deployment.

The paper is organized as follow: On the one hand, we will update recent review literatures, which deals with energy deployment. Most of documents are published on Jstor and SHSS libraries. On the other hand, we will explain the setting up of the database and how do we calibrate variables in the models. We will perform a descriptive statistic analysis for each variable we will use in our model. Then, we will present the econometric panel estimation for each photovoltaic technology (C-Si for crystalline and T-F for thin films). We complete the estimation by analyzing economically the result of regressions. And to finish, we will compare our production and installed capacity to the EPIA and Global Energy Outlook one's. We briefly conclude by suggesting some extensions of the model, the paper and the market trend in order to improve further researchs.

1. Synthesis of literature reviews

Many reviews were published these last years about the photovoltaic development. It also reflects the importance of green energy and business at the heart of today's preoccupations.

The reference paper is the Bass Model. Bass stressed that diffusion modeling is important both for firms that introduce new products and for firms that offer complementary or substitute products. Innovation diffusion is basically a learning process, and learning, being a growth process may be represented by a logistic curve. This curve describes the relationship between the spread of a technology and the cost of production. In economy, it designs the "S" curve because we observe a fast cost reduction in the time due to the economies scale. The Bass Model describes the life cycle of an innovation, depicting its characterizing phases on lunch, growth and maturity.

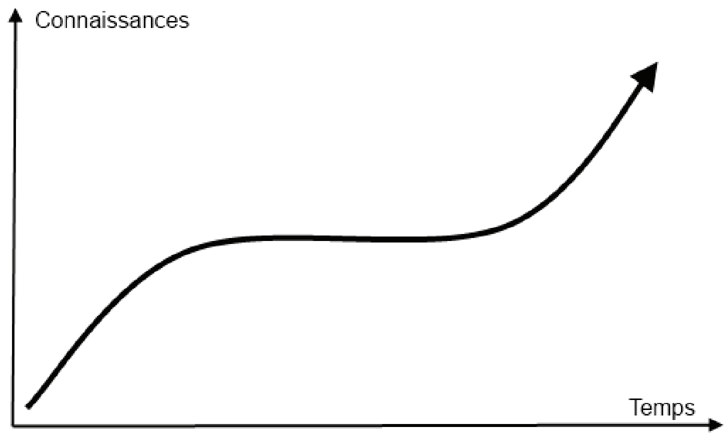

Figure1: Learning effect

Guidolin and Mortarino [7](2007) studied the PV diffusion across many countries by applying the Base Model on the PV cumulative installed power provided by IEA. They calibrated their model to different countries where PV is developed. This enables to forecast the spread of the technology in different regions, and particularly to understand the difference between each country. In the countries such as Germany and Japan where the technology became mature since a few years, they observe a weak slope in the diffusion but the trend was steadily high. In Spain, Italy and France, the diffusion process looks similar, even if Italy growth stays higher.

During recent years, industry and market have experienced an unprecedented growth. The innovation diffusion approach and specially the Bass Model have appeared the appropriate choice for analyzing this technological context.

[7] Cross-country diffusion of PV systems: Modeling choices and forecasts for national adoptions patterns.

The Bass Model used is a first-order differential equation defined by:

$$z'(t) = p\big(m - z(t)\big) + q\,\frac{z(t)}{m}(\text{m-z(t)})$$

Where *m* is the potential market, *(m-z(t))* the residual market, i-e the part of the market not reached by the diffusion of the technology. So, the residual market is moduled by 2 parameters, p for the effect of external influence and q, whose influence is moduled by the ratio $\frac{z(t)}{m}$, the odd ratio.

Bandhari and Stadler [8](2009) explained what drives skyrocketing growth of PV. The main explicative variables in their model are the learning effect by doing and the marginal production cost. They fitted time series data in order to observe the evolution of the photovoltaic price. With an interpolation of the whole market price, they forecast the breakeven price around 2020 when the cost of the grid electricity will be hardly competitive with the PV's. This is based on assumptions of a 6% growth rate of electricity price and module cost which should have been as low as 72cts/Wp. They notified the necessity to faster install photovoltaic module in order to trigger grid parity sooner and decrease production cost (explained by the learning effects).

Sandorsky (2010) investigated the link between the market risk and an energy company risk. He based his analysis on the Markowitz model linking the assess of a portfolio risk. This enables to explain that the risk of a company, which invests in PV, is not only linked to prices and deployment (which are the historical main inputs), but also to the market risk (competition, vertical integration for China companies as example), and the substitution degree between different energies deployed (coal, fuel, nuclear, solar, wind).

Let us introduce a view on the model:

$$R_{i,t} = \phi_i + \beta_{i,t} R_{m,t} + \varepsilon_{i,t}$$

Where Ri(t) is the risk of the company, $\emptyset_i$ is the substitution effects between energies and $R_m(t)$ is the market risk. Authors use a sample of renewable energy companies, drawn from the Wilderhill Clean Energy ETF (PBW). It is the oldest fund in clean energy with a capitalization around \$800 million in 2009. The empirical results are useful in establishing the importance of firm sales growth and price change to the determination of systematic risk for renewable energy companies. Other variables like firm size, debt to equity ratio and R&D expenditure have little impact.

Jenner, Chan, Frankenberg and Gabel (2012) try to understand what drives States to support renewable energies. They use a probability model

$$\lambda((t) = (P(t)/(1 - P(t))$$

λ(t) Indicates the probability to invest at a time t into green energies. This probability is driven by public interest (GDP, unemployment rate, electricity price), private interest (lobby for PV, nuclear plants, oil companies) and by control variables (FITs, regulation, solar radiation, influence of ecology deputy such as in Germany). The aim of the model is to evaluate how each variable should force a State to support renewable energy.

[8] Grid parity analysis of solar PV systems in Germany using experience curves

Different models are tested in a sample of European countries in order to measure their degree of impact on the State involvement.[9] We report here the most interesting equation estimated on the cross-country sample:

$\boldsymbol{\lambda_t}$**=3.766*ISES -2.701*UTIL +2.619*UEMP+25.741*EFAM+49.715*SOL**. If we refer to variable names, this equation means that the probability of a State to drive renewable energies depends:

- Positively on quantity of radiation (SOL), the electoral family (EFAM) at a high degree, the state unemployment (UEMP), the different Solar Energy Association (ISES)
- Negatively of the market power of utilities on state electricity market (UTIL) which is a dummy variable.

Creti and Joaug (2011) develop a discrete choice approach that differs from the standard one. The model used endogenises the net present value drivers for the PV investment: technology diffusion, learning rate and government subsidies. Based on their model, they set up a non-linear optimal model, which minimizes the total subsidies costs for a given target of installed capacity. The model is calibrated to the German PV market during 2000-2009 period and allows to simulate the market evolution until 2020. As conclusion, they have identified three periods: A priming phase with strong growth, a transition with a stable market and a mature phase with a return to growth. Moreover, to minimize costs to the taxpayer and the State, they estimate that Germany FIT will reach the levelized cost of electricity for households in 2012 and should disappear as from 2017. This assumption seems to match with the recent Germany government notification to stop all FIT policies when they will reach 52GW of PV installed.

2. Model data and variable setting up

2.1. The database

This survey is a joint act by Ecole Polytechnique and Dupont de Nemours. This partnership enables us to have an access to payware PV database.

- **Quarterly PV Integrated Market Tracker:** Built by Isuppli, it is a worldwide statistics from 2009 to 2011. It contains raw materials production (polysilicon and wafers) in Tons, PV modules produced and exchanged volume in Watt and production, benefits, Return Of Investment of the main companies.
- **Quarterly _SBQ_Data_Tables:** These quarterly reports refer to the worldwide PV supply by technology (crystalline or thin films), and the company production capacities.

[9] http://www.hhs.se/IAEE-2011/Program/ConcurrentSessions/Documents/Session%2015/062011_stockholm_jenner.pdf

- **Monthly PV_Perspectives:** A lot of graphs which indicate spot prices per country, the production capacity per country.
- **EPIA Presentation_LCOE discussion:** It is a report of EPIA (European Photovoltaic Industry Association) symposium witch show us the Levelized Cost of Energy, which is the sum of the production, the shipping, and the labour costs in the main countries where PV is deployed. They predict three schemes (low, middle and high) withing 2015. Each scheme depends on different level of weighed average cost of capital (WACC) of the installation (rooftop, commercial or ground plants). Forecasting matches a confidence interval between 345-650GW to 2030.

2.2. Variable construction

According to the database, we have chosen six different data:

- The production
- The module price
- The polysilicon, wafers and cells capacities
- The module capacity
- The learning rate

Data provide from 21 companies: Bosch-Canadian Solar-China Sunenergy-JA Solar- Jinko-Kyocera- LDK- First Solar- Motech-Ningbosolar-REC-Green Ernegy-Sanyo-Schott-Scharp-Solon-Solarworld-SunPower-Suntech-Qcells-Trina spread in four countries, which lead the PV production and installation: Germany-China-Japan and USA. According to the 7th Market Workshop of EPIA, these countries own about 70% of the worldwide capacities. Observations are quarterly registered from 2009 to 2011. Given the assumptions to set up an econometric model, we need to shift the database to make it useable. In Statistics, we suppose that observed variables must be independant from the time step to perform a good analysis. Several tests have been devised to test for the stationarity of the time series. We use Dickey Fuller and Phillips-Perron tests, which are the most used. We sample new series, for each country which are:

Pcap: Polysilicon Ratio Capacity which is the part of the polysilicon production of each country (in GTons).

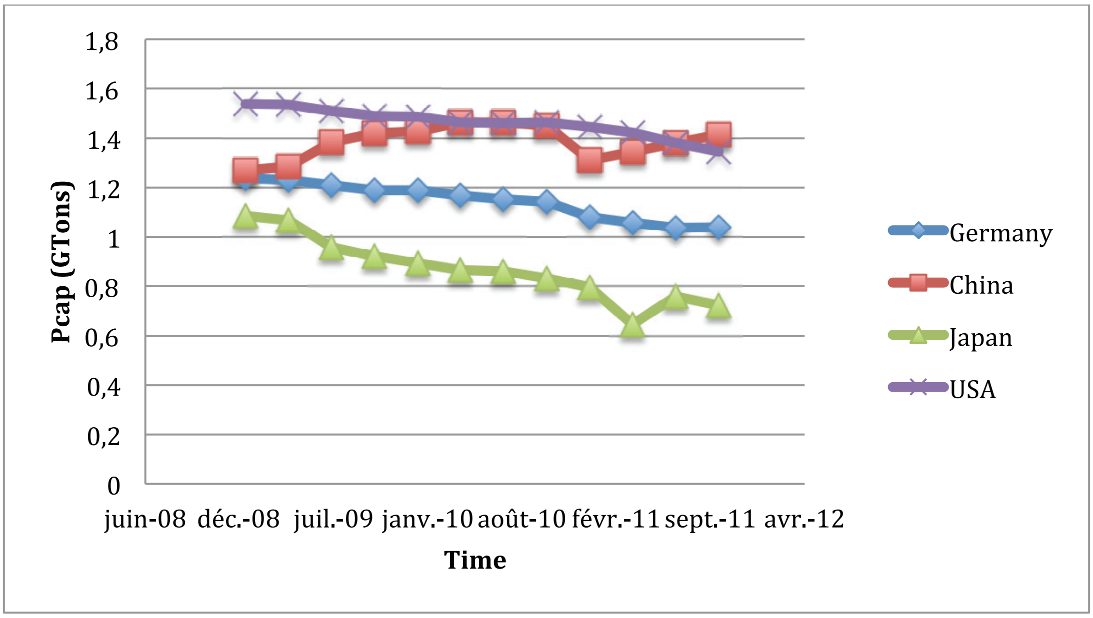

Figure 2: Polysilicon ratio capacity per country

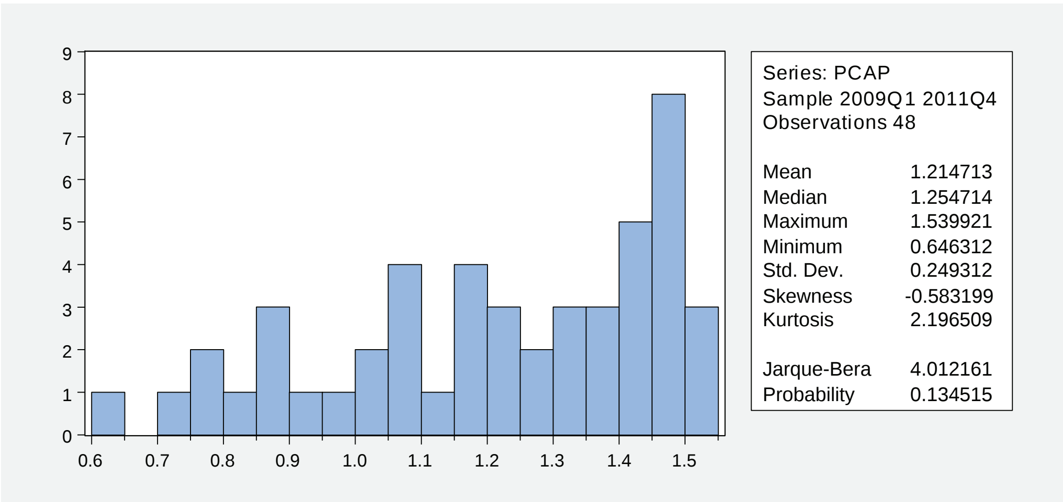

Figure 3: Statistical observation of Pcap

Silicon production is the first step of the module production. Silicon purification from silica (SiO2) found in quartz sand. It is a high energy consuming chemical process. According to the database, the worldwide demand was about 14000MW with a production capacity around 20000W At the first 2012 quarter, the world demand is multiplied per three (39000W). We can observe on the graph that USA is the country that drives the most important share of the production. The minimum production level is observed for Japan during the second quarter of 2011. The production distribution seems steered to right. This assumption is confirmed by the Skewness and Kurtosis tests.

Cap: Cells ratio capacity for each country compared to worldwide production (GW).

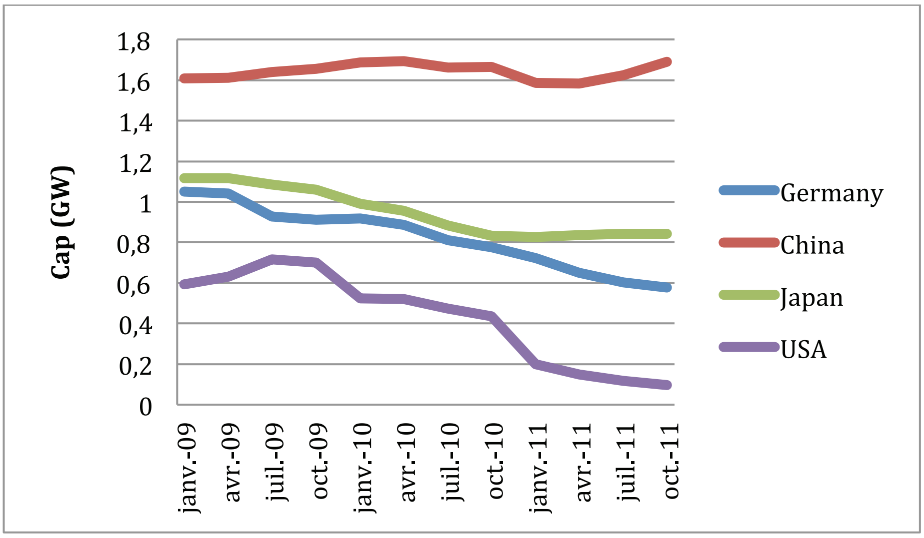

Figure4: Cells ratio capacity per country

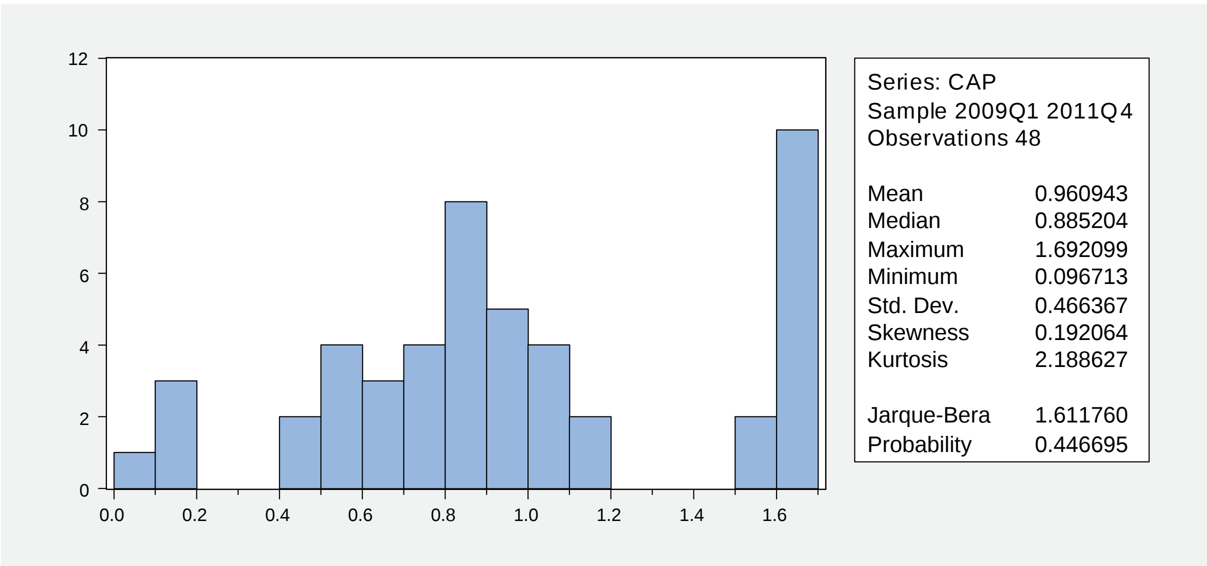

Figure 5: Statistical observation of cap

Wafers and cells production are linked,then a brick of silicon is grown. It can be single of multiple layers. Using a saw, bricks are sliced into layers called wafers. To form the cells, wafers are assembled together to form a junction responsible for the photovoltaic effect.

During the observation period, China production overpassed other countries ones. In 2009, the market demand is estimated around 2GTons against 7GTons in 2012.

China produced 1,1GTons in 2009 and 4,3GTons in 2012. This asymmetric worldwide production is observed in the figure. Values are concentrated around the average which represent China production. The distribution seems log-normal according to Jarque-Bera test (the p-value is higher than 5%).

Prod: Production it represents the level of thin films or crystalline module production in GigaWatts (GW)

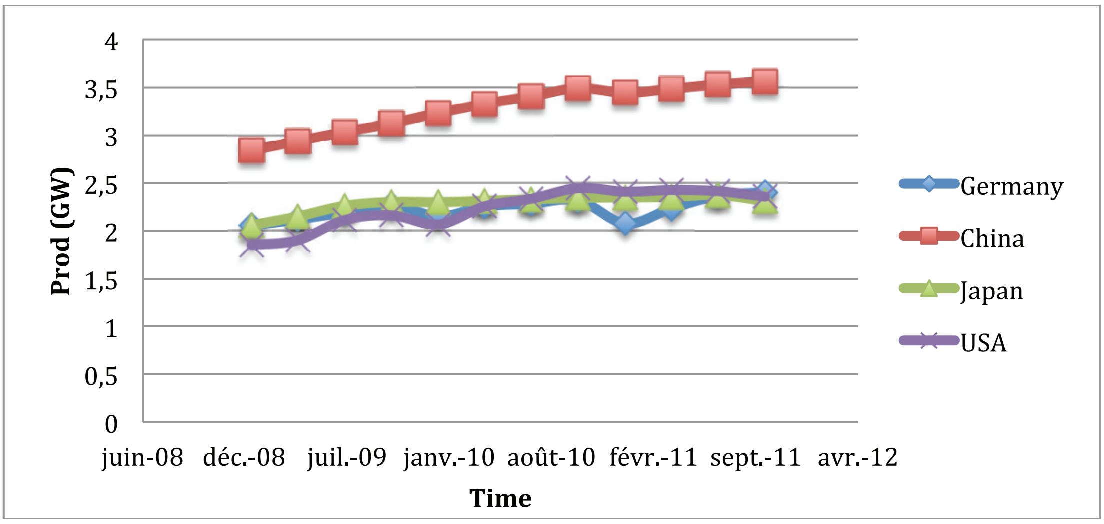

Figure 6: Production per country

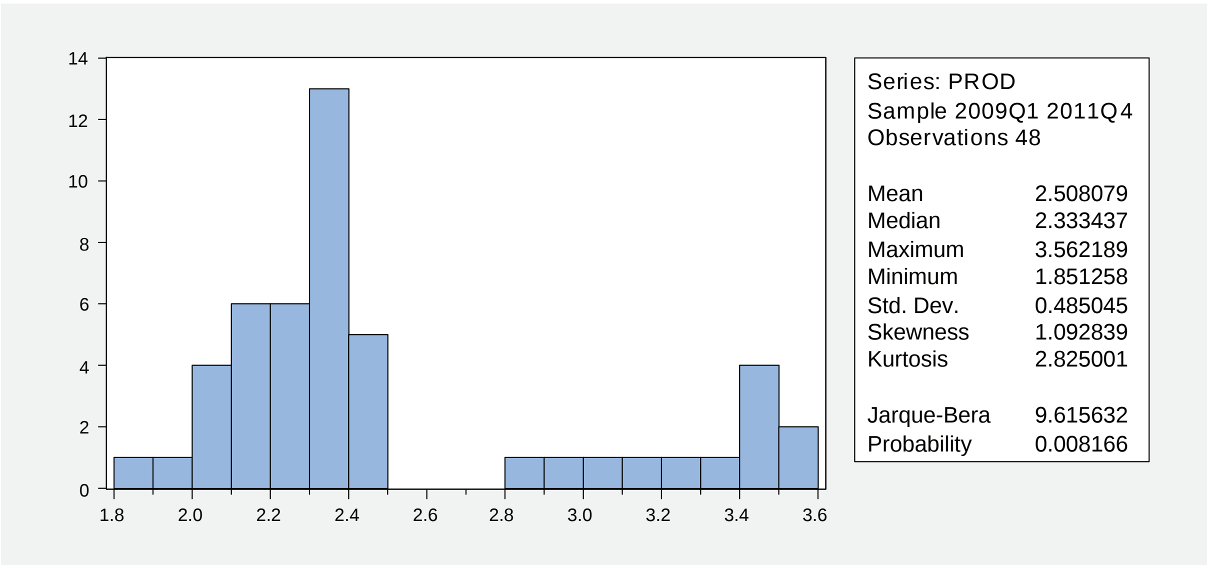

Figure 7: Production statistical observation

Historically, Germany, Japan and USA are the countries which drove the world market because they self installed PV in ground, residential or commercial plants. But since 2008, China government triggered a national policy to support renewable for export. Renewable energies represent an important share of the total exports as well as manufacturing goods. We can observe on the figure how China module productions are nowadays higher than Japan, Germany and USA cumulated. In 2012, many Germany and USA firms bankrupted due to China competition. For the crystalline module production, the volume has been multiplied by five from 2009 to 2011. More than the half depends on China manufacturing which flood the market.

Module: It is an average market price of the type of PV module in $/W from 2009 to 2011.

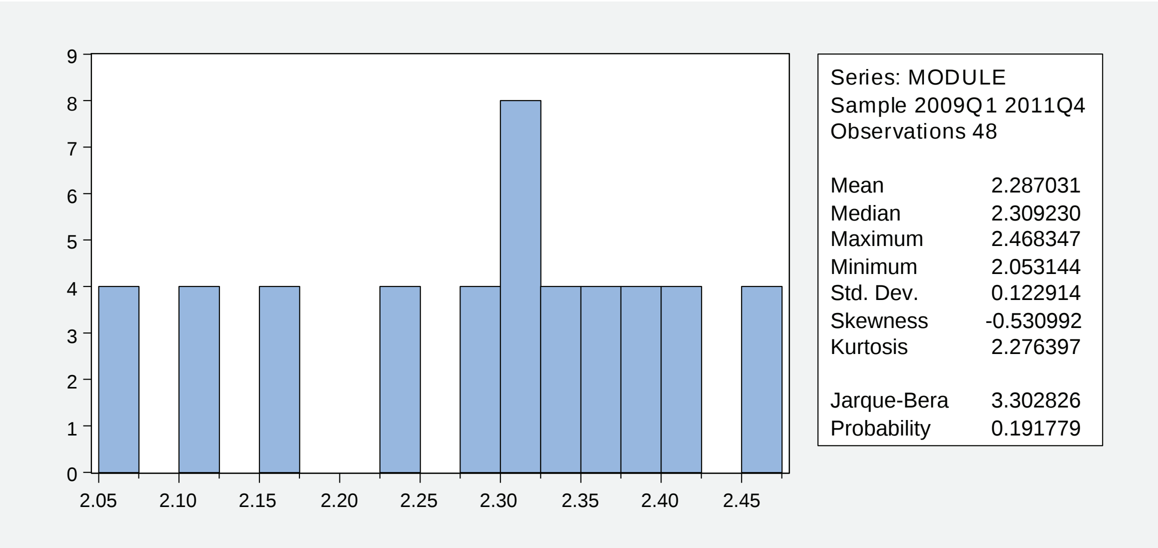

Figure 8: Module statistical observation

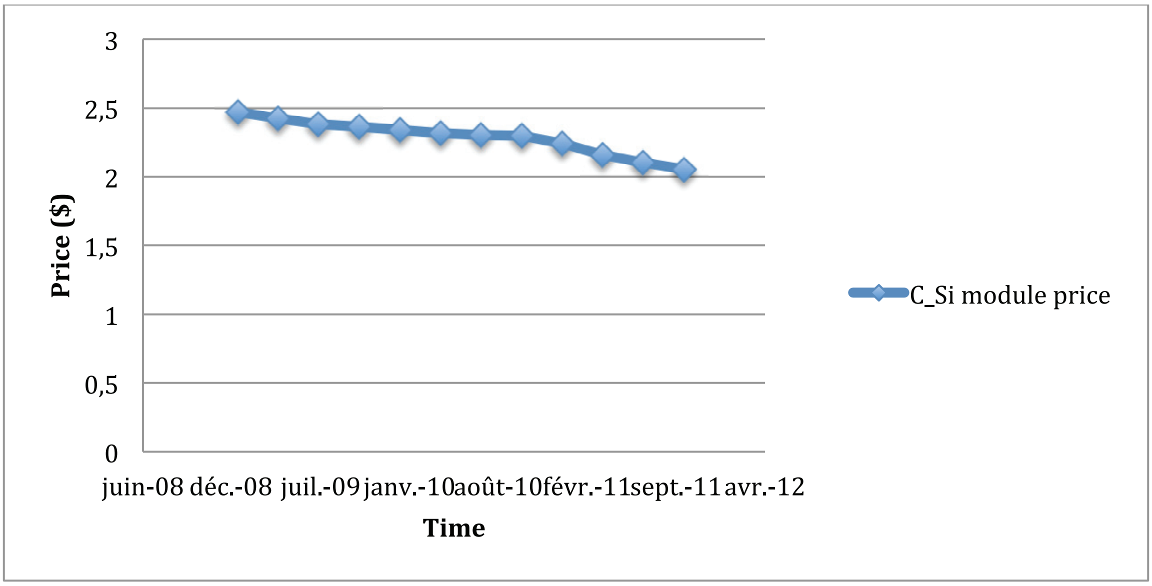

Figure 9: Module price evolution

The module price is an average market price. We consider this single variable for all country because we consider that the price is the signal which involves the entry or not of a new firm in the sector. The production price to be competitive has to be lined up of the market price. As we observe on the figure, from 2.5$/W for crystalline PV, the average price is increasingly decreased to less than 2$. We notice that it is an average market price and not the price observed per country. In Germany, they have passed under 1$/W in some regions. But according to the worldwide production, there is a real decrease trend.

Mcap: Module ratio capacity for the national volume of photovoltaic module production compared to the worldwide production. This variable enables us to observe the influence of each country to dominate the photovoltaic sector. Observations fit very well which Mathieu Galchant workpaper because we notice how Chinese companies such as Suntech, Yingli, Trina Solar and Ningbo Solar have been driving the PV production since 2010 at the detriment of Sunpower (USA) or Qcells (Germnay) which have bankrupted this year. China, as usual has the most higher ratio of module production, according to figures. Japan and Germany production shrinked a lot since 2010. Arguably, USA production drops too, but less than Germany and Japan because USA is more present in thin films technology.

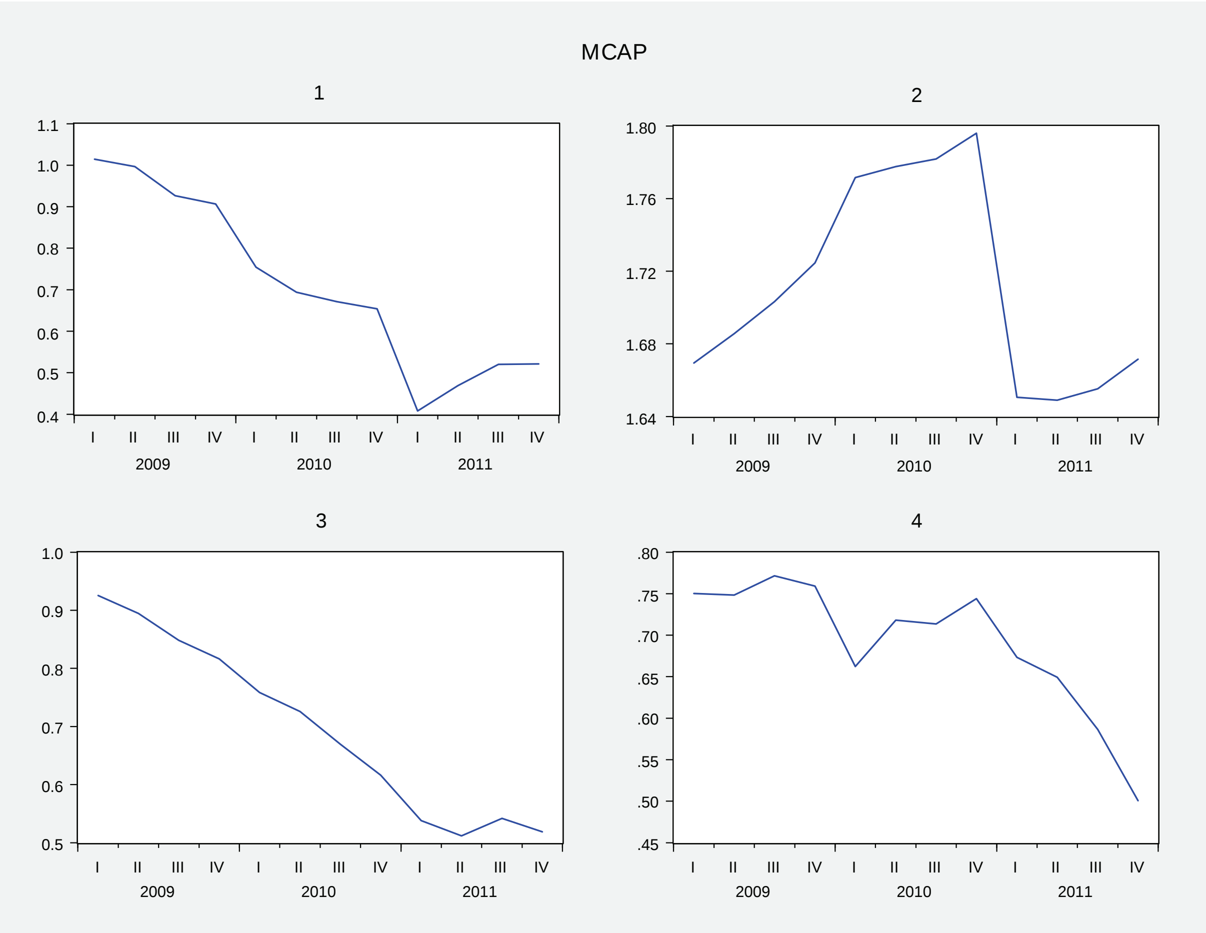

Figure 10: Module ratio capacity per country

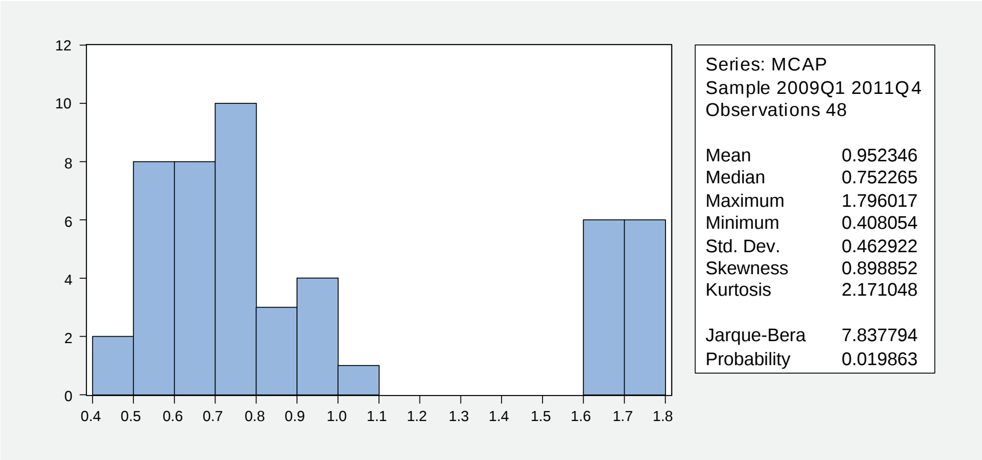

Figure 11: Module production statistical observation

B: The learning effect is on the most important variable in the model. According to literature which deals with PV deployment, the learning effect is the factor the most highlighted. The learning curve originates from observations that workers in manufacturing plants become more efficient as they produce more units[10]. The learning effect includes many parameters such as technology efficiency, innovation and labor learning. In our case, we suppose that the learning rate takes into account R&D and subsidies, which are key parameters. The central parameter in the learning curve model is the exponent defining the slope of a production function.

We consider : $C(t) = C_o * (p(t)/(p(o))^{-b}$ where C(t) is the output cost at the t time, C(o) the reference output cost (when the first production occurs), p(t) the production level at the time t , and p(o) the initial level production. The coefficient b measures the cost variation caused by the level of the production.

For each country "i", we calculate the appropriate "b" coefficient by: $b_{i,t} = (\log p_{i,t} - log p_{i,o})/(\log q_{i,t} - log q_{i,o})$

[10] Wright, 1936

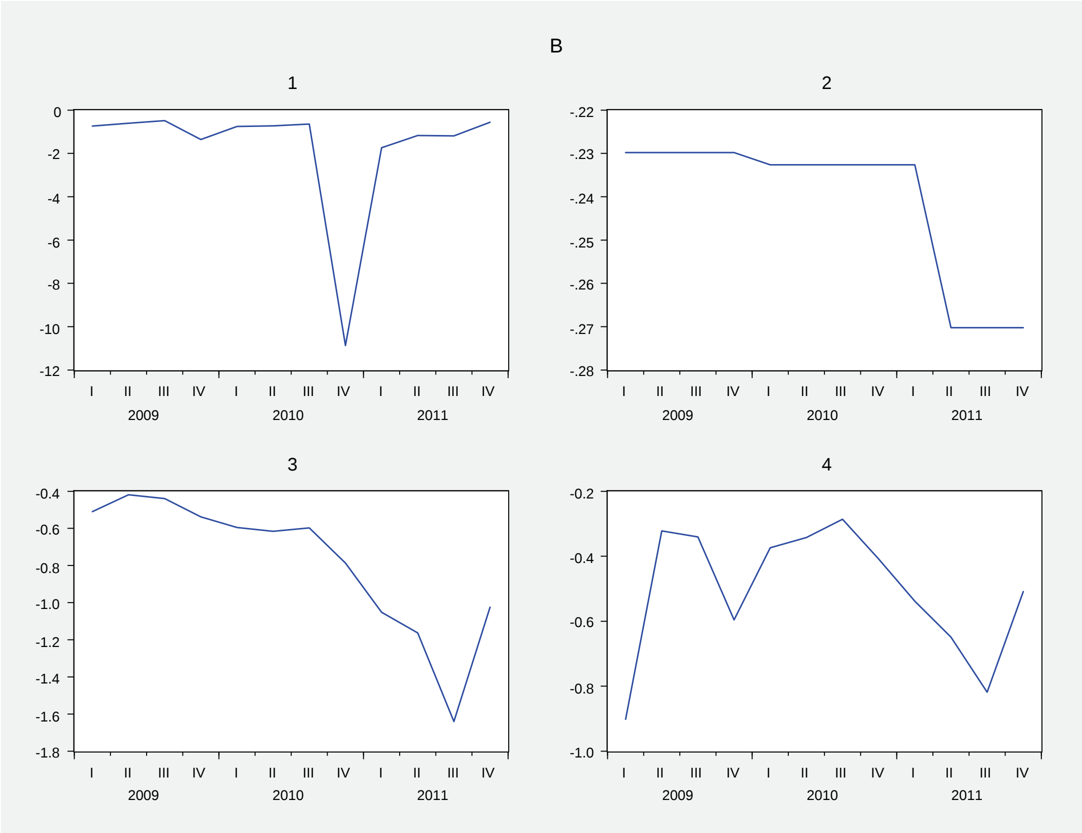

Figure 12: Learning effect observation

As we can observe, China learning effect fits well with an S curve. The price decreasing is really correlated with the production volume. According to the database, China overproduced PV modules and that's why the scale effect is more important than in other countries. The average worldwide learning effect is around -0.817. It indicates that the price will be divided by two once the production increases from 81%.

Series: B
Sample 2009Q1 2011Q4
Observations 48

Mean	-0.817502
Median	-0.538112
Maximum	-0.229819
Minimum	-10.87657
Std. Dev.	1.529583
Skewness	-6.105766
Kurtosis	40.65504
Jarque-Bera	3134.046
Probability	0.000000

Figure 13: Learning effect statistical observation

3. The model: An econometric panel structure approach

3.1. The theoretical model

3.1.1. Crystalline production function

We consider a discrete quarterly time scale "t". Crystalline technology is the most developed around the world. According to the 8th European Summit of Renewable Energy, crystalline modules represent 70% of photovoltaic installed capacities[11]. The aim of this paper is to explain the PV deployment by the production capacities, which depend on independent parameters.

The dependent variable is the production capacity per country. We assume that the production function depends on raw material prices, the average market module price, investment which fosters ratio capacities and the learning effect.

Mathematically, the production function at the time "t" for each country is:

$$\boldsymbol{p_{i,t} = \alpha_{i,t} + \beta_1 module_{i,t} + \beta_2 pcap_{i,t} + \beta_3 wcap_{i,t} + \beta_4 cap_{i,t} + \beta_5 mcap_{i,t} + \beta_6 b_{i,t}}$$

With:

- **i** for the index per country (i=1 to 4 for Germany, China, Japan and USA)
- **t** for time scale from 2009:q1 to 2011:q4
- α for intercept
- module for the PV module price
- **Pcap**, **wcap**, **cap** are polysilicon, wafers and cells production capacity compared to the worlwide's.
- **mcap** for the module production capacity
- **b** for the learning effect.

Based on Christophe Hurlin research paper (12), the panel structure is the best econometrics model to explain and to compare different countries. Indeed, this panel analysis enables to compare if there is the same production structure per country. We will try to understand if all variables have the same influence for each country or not.

Methodology

The present model highlights the PV growth depending on the leader companies of the sector. The first step consists in verifying if the production per country is homogeneous for all countries or not. Econometrically, we will test both equality and significance of each parameter of the model. This regular procedure sorts out what kind of panel estimation is the most appropriate. In other words, we will test each variable for each production function to determinate a global production level. If all variables are identics, we will set up a panel model for the aggregate production. But if we observe

[11] Solasr PV Compteting in the Energy Sector: On the Road to Competitiveness. Sept 2011

[12] L'économétrie des données de panel, Cristophe Hurlin

some differences between parameters, it involves there are specificities between each country production function.

Specification tests

There are many specifications for panel estimation[13]:

- If $\alpha_i = \alpha, \beta_i = \beta$, so the panel structure is homogeneous.
- If $\alpha_i \neq \alpha, \beta_i \neq \beta$, we reject the panel structure. All production function are different and we have to analysis independently the production
- If $\alpha_i = \alpha, \beta_i \neq \beta$, each country has different structure, the model set is not a model.
- If $\alpha_i \neq \alpha, \beta_i = \beta$, the model matches with a panel structure but there are some individual effects, according to each country specificity.

To test all these procedures, we perform the specification test of Hsiao (1986):

$\boxed{\text{Test } H_0^1 \alpha_i = \alpha, \beta_i = \beta \; ; \forall\, i}$

H1 rejected → $\boxed{\text{Test } H_0^2 \beta_i = \beta \; ; \forall\, i}$

H1 accepted → $\boxed{y_{i,t} = \alpha + \beta X_{i,t} + \varepsilon_{i,t}}$

H2 rejected → $\boxed{y_{i,t} = \alpha_i + \beta_i X_{i,t} + \varepsilon_{i,t}}$

H2 accepted → $\boxed{\text{Test } H_0^3 \alpha_i = \alpha \; ; \forall\, i}$

H3 accepted → $\boxed{y_{i,t} = \alpha + \beta X_{i,t} + \varepsilon_{i,t}}$

H3 rejected → $\boxed{y_{i,t} = \alpha_i + \beta X_{i,t} + \varepsilon_{i,t}}$

Figure 14: Hsiao specification test

We firstly test the global homogeneity panel structure. The null hypothesis consists in: $H_0^1 \alpha_i = \alpha, \beta_i = \beta; \; \forall\, i$. We use a Fisher test with (k+1)(n-1) and (nt- n(k+1)) degrees of freedom. K reflects the number of explicative variables, n the total time scale

13 Introduction Econometrics, A modern approach, Jeffrey Wooldridge

and t the observed period. We assume that $\varepsilon_{i,t}$ are independents and normally distributed[14].

In the second step, we test the significance and the equality of explicative variables for each country. $H_0^2 \beta_i = \beta\ ; \forall\, i$. We use a Fisher test with (n-1)k and (nt-n(k+1)) degrees of freedom.

And in the final step, we use test the intercept that matches with the technical progress for each country. $H_0^3 \alpha_i = \alpha\ ; \forall\, i$ We use a Fisher test too with (n-1)k and (n(t-1)-k) degrees of freedom. In the case of non-equality of the intercept, we assume each country has it own production structure which is driven by individual effects. This final test rule detects what kind of individual effects are there. According to Hausman, there are two kind of effects which are either fix or random.

We use TSP International 5.0, which is a strong and reliable econometrics software. The "*panel*" command enables to obtain all the specification test results.

PANEL DATA ESTIMATION

Balanced data: N= 4, T_I= 12, NOB= 48
Plain OLS (TOTAL)

Dependent variable: PROD
Mean of dep. var. = .712786E-02
Std. dev. of dep. var. = .253424
Sum of squared residuals = .288194
Variance of residuals = .686176E-02
Std. error of regression = .082836
R-squared = .904524
Adjusted R-squared = .893158
LM het. test = .161282 [.688]
Durbin-Watson = 1.07601 [.000,.005]
Schwarz B.I.C. = -43.0451
Log likelihood = 54.6587

Sum of squared residuals = .145161 Log likelihood = 71.1177
Schwarz B.I.C. = -24.6633

F test of A,B=Ai,Bi: F(18,24) = 1.3138, P-value = [.2625] Eqt N°1
Critical F value for diffuse prior (Leamer, p.114) = 4.3605

Fixed Effects - Individual (WITHIN)

F test of Ai,B=Ai,Bi: F(15,24) = 1.4987, P-value = [.1829] Eqt N°2
Critical F value for diffuse prior (Leamer, p.114) = 3.7642

F test of A,B=Ai,B: F(3,39) = 0.32675, P-value = [.8060] Eqt N°3
Critical F value for diffuse prior (Leamer, p.114) = 3.5585

Hausman test of H0:RE vs. FE: CHISQ(5) = 0.23415, P-value = [.9987] Eqt N°4

Figure 15: Crystalline panel estimation structure

[14] $\varepsilon_{i,t} \sim N(0, \sigma_\varepsilon^2)$

According to figure N°15, we observe that the model is balanced. Observations are regular for each country. We have 48 observations in all (12 observations for the four countries). The letter **A** accords to the intercept in the model, while **B** refers to explicative variable coefficients. Results are calculated with a Fisher test. The degrees of freedom vary depending on the restriction of each equation. To facilitate the comprehension, we use the p-value.

Equation 1 validates the null hypothesis of panel homogeneity. The p-value, which corresponds to the probability to accept the null hypothesis is higher than 5%[15]. Equations 2 and 3 strengthen this hypothesis which indicates the global homogeneity of intercept and all explicative variables.

The Hsiao specification test confirms that Japan, China, USA and Germany production function drive the worldwide PV market. Discrepancies which occurred sometimes are more influenced by cyclical economic than structural one's.

3.1.2. Thin films production function

The process is quite similar than the crystalline module. The main difference is we add one more country, Malaysia.

PANEL DATA ESTIMATION

Balanced data: N=   5, T_I=   12, NOB=   60

Plain OLS (TOTAL)

Dependent variable: PROD

Mean of dep. var. = 2.05539
Std. dev. of dep. var. = .266278
Sum of squared residuals = .351749
Variance of residuals = .628123E-02
Std. error of regression = .079254
R-squared = .915917
Adjusted R-squared = .911412
LM het. test = 1.67286
Durbin-Watson = .1817091
Schwarz B.I.C. = -60.8505

[15] In Econometrics, we usually use a 5% critical point for the null hypothesis to accept or to reject a decision.

F test of A,B=Ai,Bi: F(16,40) = 3.1693, P-value = [.0016]
Critical F value for diffuse prior (Leamer, p.114) = 4.9493

F test of Ai,B=Ai,Bi: F(12,40) = 2.5959, P-value = [.118]
Critical F value for diffuse prior (Leamer, p.114) = 4.2264

F test of A,B=Ai,B: F(4,52) = 3.5734, P-value = [.0120]
Critical F value for diffuse prior (Leamer, p.114) = 4.0800

Hausman test of H0:RE vs. FE: CHISQ(2) = 7.6005, P-value = [.0224]

Figure 16: Thin film panel estimation structure

Thin films production is heterogeneous. The p-value threshold rejects the homogeneity null hypothesis. Explicative variable coefficients are homogeneous according to Equation n°2, but the intercept is not homogeneous for countries. This non-equality of the intercept let us introduce individual effects.

Individual effects occur if variables are heterogeneous. The heterogeneity of the model provides from intercepts. Economically, each thin films module producer has a structural production system that differs from others. Innovations, are non-correlated whatever the country or the time observation.

In econometrics, we distinguish two individual effects: There are either fix or random. To determinate the appropriate effect for our model, we use Hausman test. The null hypothesis is: $H_o: Individual\ effects\ are\ random$

According to the p-value, which is lower (<0,05), we do not accept the null hypothesis of random effects. The model we will work on is: $\boldsymbol{prod_{i,t}} = \boldsymbol{\alpha_i} + \boldsymbol{\beta X_{i,t}} + \boldsymbol{\varepsilon_{i,t}}$.

In the next step, we will estimate the econometric model, using a panel estimation method and determinate which variables are econometrically significance. These variables will be supposed to driven the PV worldwide market.

3.2. The econometric model

The objective here is to regress the photovoltaic production on explicative variables. According to the previous methodology, we use Eviews 6.0 and 7.0 versions to run the estimation.

3.2.1. Crystalline estimation

Dependent Variable: PROD				
Method: Panel Least Squares				
Date: 09/21/12 Time: 12:33				
Sample: 2009Q1 2011Q4				
Periods included: 12				
Cross-sections included: 4				
Total panel (balanced) observations: 48				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
MODULE	-0.110894	0.297559	-3.372679	0.0711
PCAP	1.782311	0.601552	2.962855	0.0050
WCAP	-1.836926	0.789432	-2.326896	0.0249
CAP	1.439234	0.668334	2.153465	0.0371
MCAP	0.894005	0.814940	1.397019	0.1279
B	-0.577727	0.024911	-1.610174	0.1250
R-squared	0.852494	Mean dependent var		-0.042852
Adjusted R-squared	0.861124	S.D. dependent var		0.425102
S.E. of regression	0.165093	Akaike info criterion		0.298999
Sum squared resid	2.951527	Schwarz criterion		0.532899
Log likelihood	-1.175969	Hannan-Quinn criter.		0.387390
Durbin-Watson stat	1.943774			

Figure 17: Crystalline econometrics estimation

The panel least square method is applied for the estimation. Cross-sections refer to the panel structure. Each cross section corresponds with a country. R^2 which makes up close to the quality of the estimation is closed to 90%. The model seems good as so long as 90% of explicative variables (module, pcap, wcap, cap, mcap, b) fit well the production. Module and raw material prices are all significance if we consider a 5% critical point for the p-value. We have to upgrade this threshold to 15% for the learning effect and module production capacities. Let us keep in mind these values are compared with a Student[16] test.

Module prices, wafers capacities and the learning effect are inversely related to the production capacities. Their coefficients are all negative because, if the price of the technology decreases, the willingness to pay for the technology will be appreciated. In another hand, the learning effect that is driven by scale effects confirms Cobb Douglas analysis. Indeed, in economics we used to consider that the marginal productivity of inputs is proved to be very closed to improved measure of production over time.

[16] For the Student test, the null hypothesis consider that the coefficent of the variable test is not significance. So the variable does not influence the production. The optimal situation is to reject the null hypothesis.

Polysilicon, Cells, and module ratio capacities are positively related to the production capacities according to coefficient signs. Raw material exploitation enables to improve the production capacity.

In order to validate the model, we will perform the main tests which respect the least square hypothesis:

- $\boldsymbol{\varepsilon_{i,t} \sim N(0, \sigma^2)}$
- $\boldsymbol{E(\varepsilon_{i,t}) = 0}$
- $\boldsymbol{E(\varepsilon_{i,t}\varepsilon_{i,s}) = \begin{cases} \sigma^2 \text{if } t = s \\ 0 \text{ if } t \neq s \end{cases}}$

The first hypothesis assumes the distribution of resid should be log-normal. We perform a Jarque-Bera test.

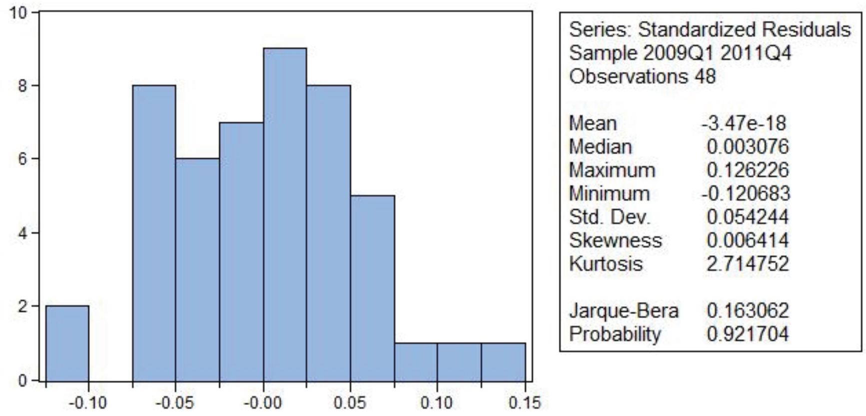

Figure 18: Resid analysis

As we observe, the resid distribution fits well with the normal distribution. Jarque Bera normality test enables to validate the normality of the distribution with a 92% p-value threshold.

Hypothesis 2 and 3 refer to the homoscedasticity and non autocorrelation. Observations are supposed to be independent and identical distributed. Hence, each variable must be uncorrelated with other variables. Homescedasticity assumption assumes resids are identical whatever the time sample. Non autocorrelation of resids suppose there is no link between different time observation.

Using respectively Goldfeld-Quandt and Durbin Watson –White tests, we verify homoscedasticity and non autocorrelation. To conclude, hypothesis of Homescedasticity and non autocorrelation are non violated because of test results.

Dependent Variable: RES2^2
Method: Panel Least Squares
Date: 08/20/12 Time: 11:27
Sample: 2009Q1 2011Q4
Periods included: 12
Cross-sections included: 4
Total panel (balanced) observations: 48

Variable	Coefficient	Std. Error	t-Statistic	Prob.
MCAP^2	-0.000652	0.006362	-0.102553	0.9188
B^2	9.55E-06	4.30E-05	0.222166	0.8252
MODULE^2	0.014192	0.030488	0.465487	0.6438

R-squared	-0.664139	Mean dependent var	0.003559
Adjusted R-squared	-0.738100	S.D. dependent var	0.004360
S.E. of regression	0.005749	Akaike info criterion	-7.419214
Sum squared resid	0.001487	Schwarz criterion	-7.302264
Log likelihood	181.0611	Hannan-Quinn criter.	-7.375018
Durbin-Watson stat	1.995618		

Figure 19: Homoscedasticity test

Dependent Variable: RES2
Method: Panel Least Squares
Date: 08/20/12 Time: 11:59
Sample (adjusted): 2009Q2 2011Q4
Periods included: 11
Cross-sections included: 4
Total panel (balanced) observations: 44

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.001323	0.008406	-0.157449	0.8756
RES2(-1)	0.512306	0.145489	3.521272	0.0010

R-squared	0.227932	Mean dependent var	0.002024
Adjusted R-squared	0.209549	S.D. dependent var	0.062310
S.E. of regression	0.055399	Akaike info criterion	-2.904139
Sum squared resid	0.128898	Schwarz criterion	-2.823039
Log likelihood	65.89105	Hannan-Quinn criter.	-2.874063
F-statistic	12.39935	Durbin-Watson stat	1.891035
Prob(F-statistic)	0.001049		

Figure 20: Autocorrelation test

Economic analysis

Crystalline module production estimation confirms the importance of raw materials, module prices, capacities and learning effects in the photovoltaic skyrocketing growth. With a global market around 60-70GW installed, crystalline module is the leading technology. Installations depend mainly on ground and rooftop installations. In 2011, polycrystalline modules represent 47% of the market, against 39% for monocrystalline[17]. The module price fluctuates lower than 1.2-1.5 nowadays.

The increasing price of grid electricity enables photovoltaic electricity generated to reach sooner the grid parity in Germany and Japan for example. Because of the globalization, competition and currency change rates, national companies try to reach a worldwide market to extend their business. It involves high investments in factories to reach lower production cost: It's the learning effect impact.

But due to the recession, production capacities exceed the market capacity. Overproduction is another reason of the decreasing price. In the *2012 PV Market Research*[18], we observe from 2010:q3 to 2012:q3 that the production capacity switches from 8GW to 12GW (a net growth of 50%); while the real production slows down around 6-7GW. The shipment volume slightly climbs from 6GW to 6.6GW. Before 2010, shipment capacities adjusted the production volume. As we observe the database, the penetration of China companies such as Suntech, Yingli, Ninglo Solar (which represent the first three) in each step of the production chain (raw materials-production-shipping) from upstream to downstream triggered and accelerated the PV deployment in the world. Mathieu Glachant in his research paper[19] emphasis on China, which is the only country in the world which does not take into account to it national market to foster national companies growth.

In developed countries, photovoltaic deployment is linked with the willingness to pay, set up by governments. Support policies and financial incentives facilitate electricity production substitution. In our model, we do not take into account any support policies because they fluctuate a lot during last years. Indeed, Germany decides in August to stop all PV policies while they will reach 52GW installed. But this cap of 52GW does not represent the end of the Germany PV industry. We assume that it will not be significance because with a macroeconomics point of views, incentives are just important to facilitate a penetration of a technology. After some years of experience, learning effects, innovation and customer behaviors influence the most the choice of a technology.

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[17] Navigant Consulting, Inc, Global Supply and Demande Balance, 2012

[18] www.pvmarketresearch.com , Ash Sharma

[19] Innovation and international technology transfer : The case of Chinese photovoltaic industry

3.2.2. Thin film estimation

Dependent Variable: PROD				
Method: Panel Least Squares				
Date: 09/25/12 Time: 13:37				
Sample: 2009Q1 2011Q4				
Periods included: 12				
Cross-sections included: 5				
Total panel (balanced) observations: 60				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.249642	0.197953	-1.261121	0.2128
CAPACITY	1.064859	0.085239	12.49265	0.0000
PRICE	-0.095821	0.106322	-2.901232	0.0315
	Effects Specification			
Cross-section fixed (dummy variables)				
R-squared	0.931898	Mean dependent var		2.055392
Adjusted R-squared	0.924188	S.D. dependent var		0.266278
S.E. of regression	0.073317	Akaike info criterion		-2.278776
Sum squared resid	0.284893	Schwarz criterion		-2.034436
Log likelihood	75.36327	Hannan-Quinn criter.		-2.183201
F-statistic	120.8741	Durbin-Watson stat		1.836766
Prob(F-statistic)	0.000000			

Figure 21: Thin film estimation

Thin films model has a panel structure with fix effects. We use a **within estimator** and perform a LSDV[20] regression. Fix effects involve a specific production structure per country. Hence, Eviews adds dummies variable[21] for each country to differentiate the production structure. The least square estimator is centered on individual medium. The production estimation is written as:

$y_{i,t} = \alpha_i + \beta' X_{i,t} + \varepsilon_{i,t}$ Where

$$\widehat{\boldsymbol{\beta}_{LSDV}} = [\sum \sum_{T}^{N} (\boldsymbol{x}_{i,t} - \bar{\boldsymbol{x}}_i)(\boldsymbol{x}_{i,t} - \bar{\boldsymbol{x}}_i)']^{-1} [\sum \sum_{T}^{N} (\boldsymbol{x}_{i,t} - \bar{\boldsymbol{x}}_i)(\boldsymbol{y}_{i,t} - \bar{\boldsymbol{y}}_i)']$$

$$\hat{\alpha}_i = \bar{y}_i - \hat{\beta} \bar{x}_i$$

[20] Least Square Dummy Variable

[21] Dummy variable is a binary variable (1,0).

$\overline{x_\iota}$ *and* $\overline{y_\iota}$ *represents the mean per country of production and explicative variables. The LSDV Estimator is centered on each national production mean.*

For thin films production estimation, we do not take into account raw materials as so long as they are significance yet. R^2 is closed to 93% and indicates the good specification of the model. Capacity, module prices and innovation explain more than 90% the production capacity. As we observe for silicium module, module capacities are positively related to production between there is a positive correlation between investment and production. In the other hand, there is a negative relationship between price and production. All coefficients seem significance according to the Student Test results.

We perform a Wald test, which is a restriction test on coefficients, and no parameters seem null. Durbin Watson stat which is closed to 2 confirm the non autocorrelation in the model (we strength this hypothesis by the White test), and according to Goldfed & Quandt test, there is no homoscedasticity in the model. To conclude, all hypothesis are validated.

Economic analysis

Thin film modules represent the minor technology. The cheap price and the low yield do not foster it. Thin films represent around 14%[22] of PV installed around the world. The preferential use is for ground plants because the technologies become financially more attractive for ground installation due to the size. This is possible because of the lower capital invested than crystalline modules. According to EPIA Levelized Cost of Energy, the yield of thin film modules switches from 6% to 12% since 2008. Module prices represent 49% of the installed price in 2010. The price per module decreases from 2$ to less than 1$ at the beginning of the year. In the same time, the production capacity increases by 300% (from 600MW to 2000MW at the beginning of 2012) while the demand market steps up from 300MW to 1200MW. The thin film is overproduced like crystalline. By contrast with crystalline technology, China is not the leader: Japan and Malaysia produce more than 70% of worldwide capacity followed by Germany and USA.

This ranking stress China penetration policy. As so long as thin film is not the technology the most deployed, China interest to invest into this sector is neglected. According to the database, the shipping volume is lower than the production capacities for thin film technology.

[22] 2012, Navigant Consulting, Solar Services Program

4. Forecasting photovoltaic deployment path

4.1. Empirical analysis: Global Energy Outlook for PV until 2016

Europe has developed an annual market less than 1GW in 2003 to market over 22GW in 2011. Given the difficult economics and decrease of PV support policies, the market expects stabilization compared to 2010. Italy became the top PV market, with 9,3GW installed followed by Germany with 7,5GW. As it has for several years, Europe has it leadership shar of the global PV market.

Outside Europe; China, Japan and USA joined the group of countries with more than 1GW installed recently. This ranking highlights that producing countries are the same where the technology spreads the most.

In 2011, new PV installations in the rest of the world accounted for 7,5GW[23], compared to 3GW in 2010. All are expected to growth beyond 2012. The development of the market outside Europe is bipolarized for the new market: At the top, there are China, which try to develop it national installation market, Australia and Canada. At the down of the scale, there are India with 300MW installed in 2011, Israel with 140MW, and Africa for 450MW and other regions for 340MW.

At the beginning of 2012, the market was closed to 30GW installed. The sector is at the crossroad of its development around the world. Even if the expected market outside Europe will not compensate Europe recession, in its moderate scenario, EPIA expects 20GW in 2012 due to recession and trials against China, 20,7GW in 2013 and 27GW in 2014. The lower trend compared to the previous years is because of the capacity of future market not to be able to installed GW capacities. This evolution is will depend mainly to the ability of policymakers and governments.

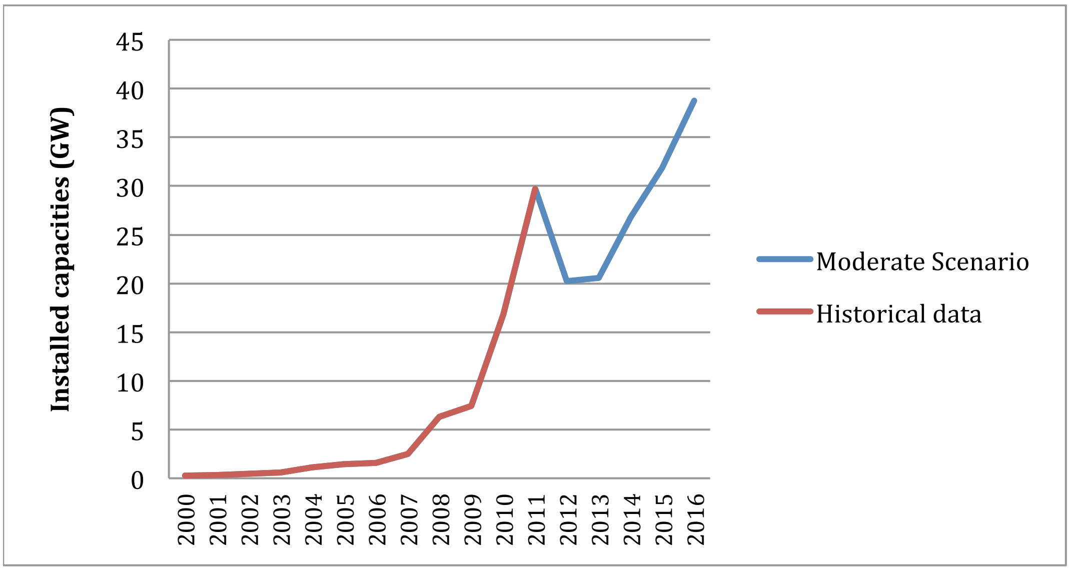

Figure 22: Global EPIA moderate scenario

[23] This includes China, USA and Japan. Except these countries, only 1,7GW represent the real capacity installed for developing countries and Canada, Australia.

As we observe on the figure, PV annual installed capacity will be increasingly on growth. According to EPIA data, the Rest of the World, China and Europe will drive the deployment. Indeed, from 2011 to 2014, ROW is expected to have a steady growth around 87%[24] year on year Rest of World is leaded by India, Australia and South Africa mainly. China will climb up from 3GW nowadays to 3.5GW yearly installed in 2014. Europe installation will shrink a little compared to the previous years with an average growth around 9,2GW installed.

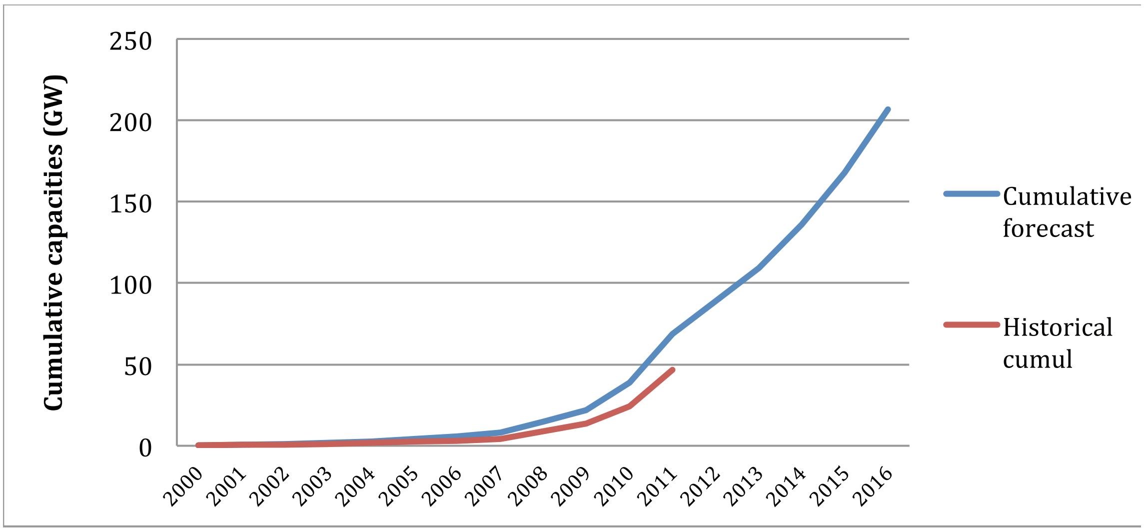

Figure 23: Cumulative installation: Global EPIA moderate scenario

This figure predicts 210GW of PV installation over 2016. Compared to 63GW in 2011, the potential market will increase of 500%. It represents 2/3 of the worldwide nuclear[25][26] plants installed in 2011. In view of a nuclear reactor capacity, it is apparent that photovoltaic will be at the heart of electricity production during years to come.

EPIA economists expect ROW[27] capacities will switch from 3GW to 14GW until 2016. China installation will be up to 21GW compared to the 6GW installed presently. And to finish, Europe will be always leader with 100GW until 2016. But European countries share will decrease in the time. Indeed, Europe will represent 50% from 2015 of PV installed capacities, contrary to their 70% nowadays share.

[24] With 1GW, 1.5GW , 2,5GW and 3GW in 2011-2012-2013-2014

[25] Nuclear installation are estimated to 345GW

[26] http://fr.scribd.com/doc/50810770/72/Puissance-electrique-installee-dans-le-monde

[27] It does not include China

4.2. Forecasting optimal path

In agreement with EPIA conclusions about developing countries will take up PV growth, we consider in our forecast that Africa, India and South America will grow up at 63%[28] in average yearly. At the contrary of developed countries, emergent markets shift to off-grid installation. Off-grid represents more than 80% of installation in developing countries, compared to Germany where off-grid represents less than 6% of PV installations. Even if off-grid is more expensive because of storage in the base of system, the main advantage is the quick breakeven with the grid parity.

We consider a quarterly forecast time step because of our observations. At the contrary of EPIA yearly scenario, a quarterly approach provides a best fitting. We do not consider any support policies because of the cost. Creti & Joaug, in their research paper stress that Germany will invest around 70[29] billion of euros to reach the grid parity until 2017 in the optimal scenario. It is practically impossible for developing countries to invest so much money because it is higher than their own gross domestic product. Meanwhile, photovoltaic development will be fostered by the important solar irradiation[30], lack of electricity and NGO or companies willingness to develop energy access. For example, Schneider Electric sets up BipBop program, which spreads access to a safe, affordable and green energy for those who need it, the most. Morever, South Africa invested 1,3 billion $USD to install a100MW[31] central recently.

According to the model parameters, we focus the prediction on raw material prices, module price, module production capacities and learning effect. We make a linear interpolation of each variable to obtain optimal trajectory for 2012q2: 20015q1 according to historical observation and IHS Suppli market reports. Concerning module price, we observe a 45% decrease from 2009:q1 to 2011:q4. For our model, we assume a net decrease of 7[32]% quarterly. Then, we get crystalline and thin films module production prediction. On the other hand, based on overproduction capacities, we consider installation represent 80% of production level in 2011, 85% in 2012 and 90%[33] in 2013 and 2014. We perform calibration with *MAPLE* and *Excel*. To finish, we set a worldwide PV installation curve which cumulate thin films and crystalline technologies that we compare with EPIA scenario.

---

[28] We chose 23% as optimal growth rate because in EPIA historical data, these markets owe 3% of PV installation. And between 2001 and 2009, PV installation grows up at 65% in these regions.

[29] This is the cumulative cost of FIT policy since 2009

[30] According to the world solar irradiation Chart, Africa-Asia and South America get more than 3000KWh/m^2/year.

[31] http://terangaweb.com/un-projet-davenir-le-csp-en-afrique-du-sud/

[32] 7% of quarterly evolution means 31% of annual evolution

[33] From 2009 to 2011, shipping and installation represent 80-89% of PV production. Even if production decreased in Germany and USA, China and Malaysia will compensate the global production. New market will absorb slowly overproduction. We consider a 15% rate accordingly to the installation capacities.

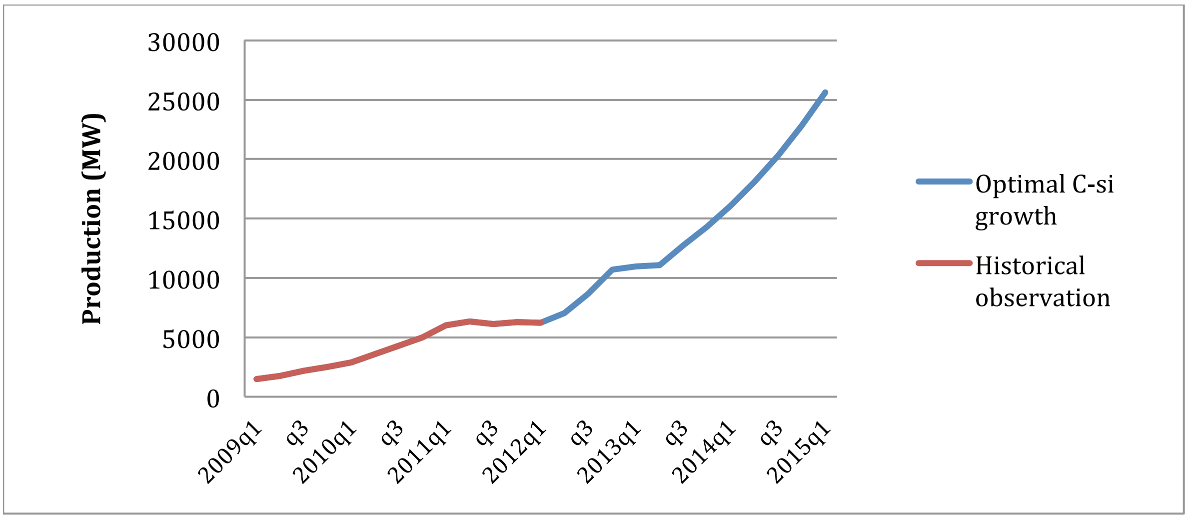

Figure 24: Forecasting scenario for C-Si

On this figure, we observe a little slowdown of production until 2013. This situation is because of bankruptcies in 2012[34]. Moreover, USA and European Union decided to bring China to trial because of dumping. USA voted a 30% tax rate on every China module imported. A wind of recession is blowing over the PV market. Indeed the growth rate of production during 2011-2012 is inferior than the previous period.

Meanwhile, production growth is expected to reboot at the second quarterly of 2013. This situation is explained by the catch up of developing countries. Their important GDP and the interest to get an access to a clean energy enable PV market to switch from developed countries to the new market. PV is going to be the most competitive renewable energy available in the world. We expect a 25GW yearly produced over 2015.

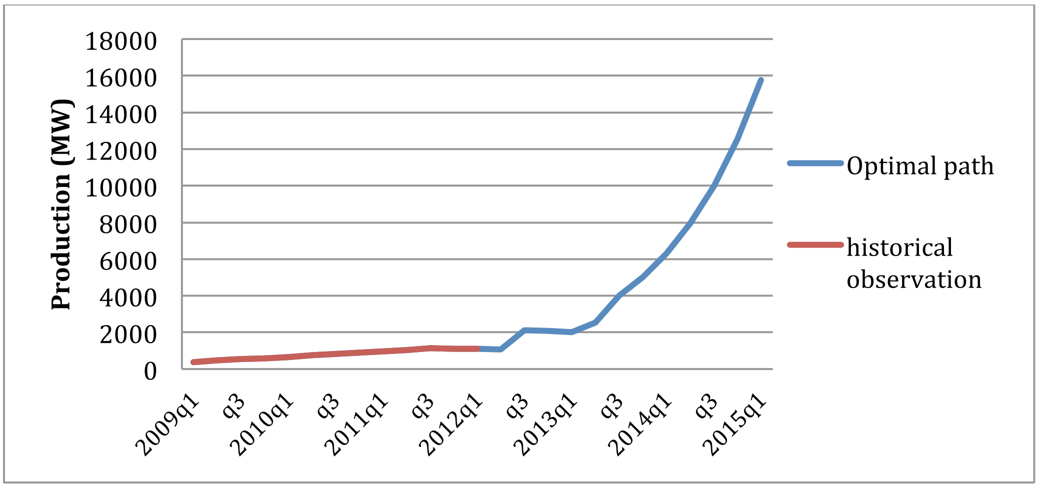

Figure 25: Thin film forecast

[34] Q-cells for example

About thin films technology, the slow down is less important than the crystalline production. Thin films are the minor technology and their deployment is more effective for ground installations. Generally, they are installed in the production country. They are very sensitive to each national market. Thin film production is driven by national policies to support the technology. In our forecasting, we hope a steadily growth over 2015. We expect around 16GW yearly produced.

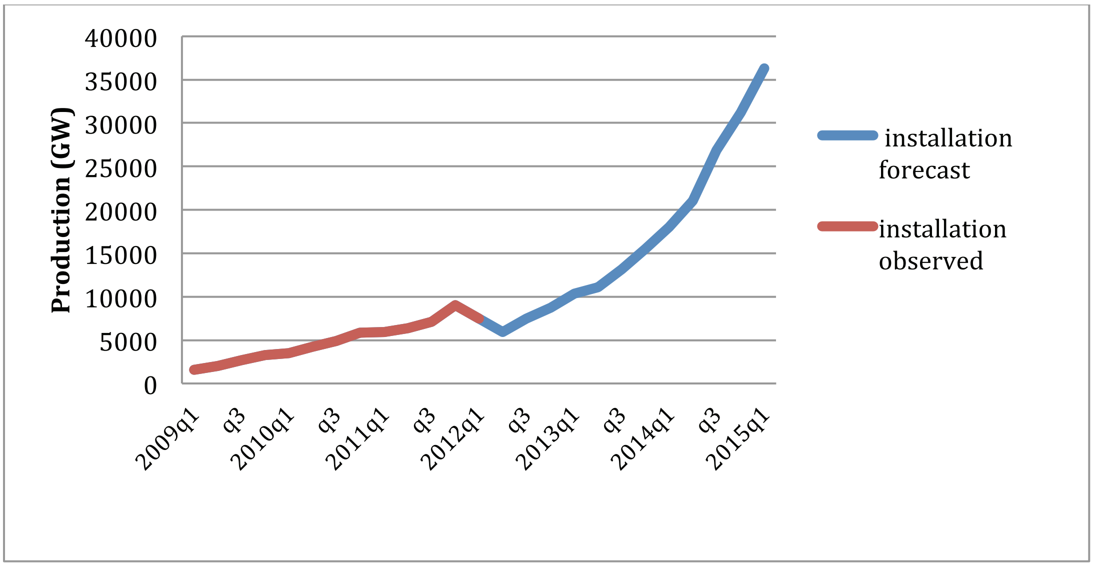

Figure 26: Cumulative scenario

As we indicate previously, installations will represent 80-90% of the worldwide production. We set up an aggregate installation function based on our production prediction. This function is a thin film and crystalline cumulative. Generally, the photovoltaic installation will progress in the world. This growth path is because of developing countries, which will represent around 19%[35] in 2015. We expect 36GW installed over 2015. Compared to EPIA scenario, we are a little bit higher because they predict 31.9GW in 2015. This differential is inducted by the importance we commit to new market (China, India and Africa).

If we consider cumulative installations, we expect PV will reach 206GW installed in 2015 against 170GW for EPIA moderate scenario. Discrepancies observed respect different assumptions and data used. Each scenario complies with objectives fixed. Our roadmap defines the optimal path of photovoltaic deployment, according to historical installations, production evolution and hypothesis on input prices. We take into account total production and installation capacities.

[35] Considering the 36GW installed in 2015, we predict 27GW for developping countries against 9GW for new market.

CONCLUSION

Photovoltaic is positioning itself as the heart of renewable energy program. No other technology has reached enough maturity and deployment as PV did: high price decreasing, better yields, technical innovation, learning effects and policies support. Arguably, China entry in the market as producer has upset the market trend.

This paper develops an econometric model, which is very different from the standard ones: Based on an empirical study of the production function of countries, which drive the production, we set up a panel model to estimate production determinants. Then, we calibrate a worldwide production function depending on thin film or crystalline modules in order to forecast the optimal path until 2015. The model adequately describes the evolution of production and installation during 2012:q1 to 2015:q1. We identify a slowdown period until 2013 followed by a growth path until 2015. Our scenario is quite similar to the EPIA optimal one's. The prediction model highlights the importance of developing countries in the future installation, even if there will not be any incentive policies. That is why the strengthen analysis we do seems to be closed to EPIA moderate scenario and historical trend.

As recommendation, the model would greatly gain in accuracy if we studied more countries. Our approach could be complete by a global panel analysis that would analyze PV deployment in each country. On the other hand, we based our estimation on DuPont database, which is short to predict further. It would be more accurate to get a broader range database. And why not, take into account electricity price as a variable to compare with the levelized cost of energy of PV system.

ANNEXES

```
TSP Session [I/O Console]   12:26:43 20-Sep-2012

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                    |        this copy licensed         |
                    |          for use by:              |
                    | TSP/GiveWin 5.0 User   #50AGT0054 |
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                              TSP Version 5.0
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              In case of questions or problems, see your local
→ TSP
              consultant or send a description of the problem
→and the
              associated TSP output to:

                              TSP International
                               P.O. Box 61015
                             Palo Alto, CA 94306
                                    USA

 Enter TSP statements:

   1 ? load (file='C:\users\leomicky\desktop\csi.xls' , format=E
→XCEL);


 Current sample:  1 to 48
   2 ? panel (id=i, time=t, byid) prod module pcap wcap cap mcap
→ b


                      PANEL DATA ESTIMATION
                      =====================

 Balanced data:  N=     4, T I=   12, NOB=     48

 Plain OLS (TOTAL)
 =================

 Dependent variable: PROD

        Mean of dep. var. = .712786E-02
   Std. dev. of dep. var. = .253424
 Sum of squared residuals = .169302
    Variance of residuals = .412931E-02
 Std. error of regression = .064260
                R-squared = .943912
       Adjusted R-squared = .935704
             LM het. test = .160457 [.689]
            Durbin-Watson = .964954 [.000,.002]
         Schwarz B.I.C. = -53.8763
           Log likelihood = 67.4255

            Estimated    Standard
 Variable  Coefficient     Error       t-statistic    P-value
 MODULE    -1.66721      .094280       -17.6836       [.000]
 PCAP      -.094298      .162811       -.579189       [.566]
 WCAP      .088328       .198287       .445455        [.658]
 CAP       -.091618      .176382       -.519431       [.606]
 MCAP      1.04058       .193927       5.36585        [.000]
 B         -.710800E-02  .501776E-02   -1.41657       [.164]
 C         .248666E-02   .945081E-02   .263116        [.794]

 Varying slopes and intercepts (BYID)
 ====================================

 Sum of squared residuals = .067870   Log likelihood = 89.3635
           Schwarz B.I.C. = -35.1667

 F test of A,B=Ai,Bi:  F(21,20) = 1.4233,  P-value = [.2170]
 Critical F value for diffuse prior (Leamer, p.114) =   4.2279
→

 OLS on individual means (BETWEEN)
 =================================

 Dependent variable: PROD

        Mean of dep. var. = .712786E-02
   Std. dev. of dep. var. = .083648
 Sum of squared residuals = .541668E-33
    Variance of residuals = 0.
 Std. error of regression = 0.
                R-squared = 1.00000
       Adjusted R-squared = 1.000000
             LM het. test = .407720 [.523]

            Estimated    Standard
Page: 1 of 2
```

Figure27: TSP panel specification test

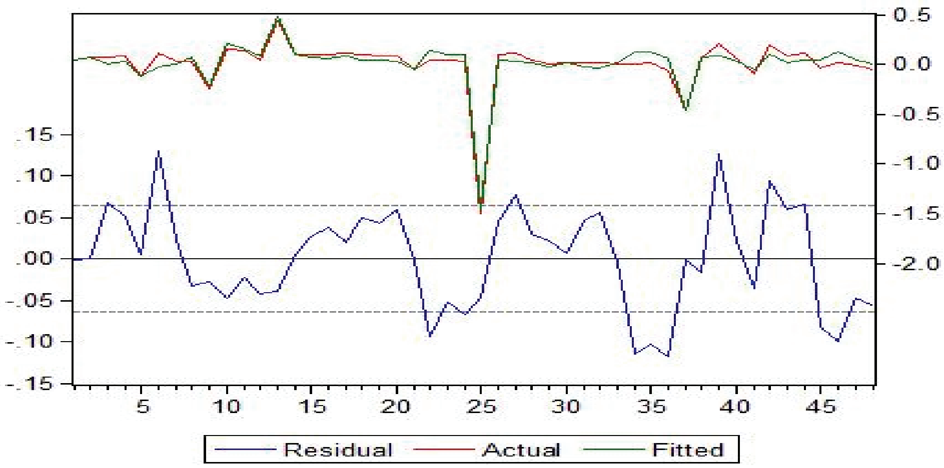

Figure28: Resid structure

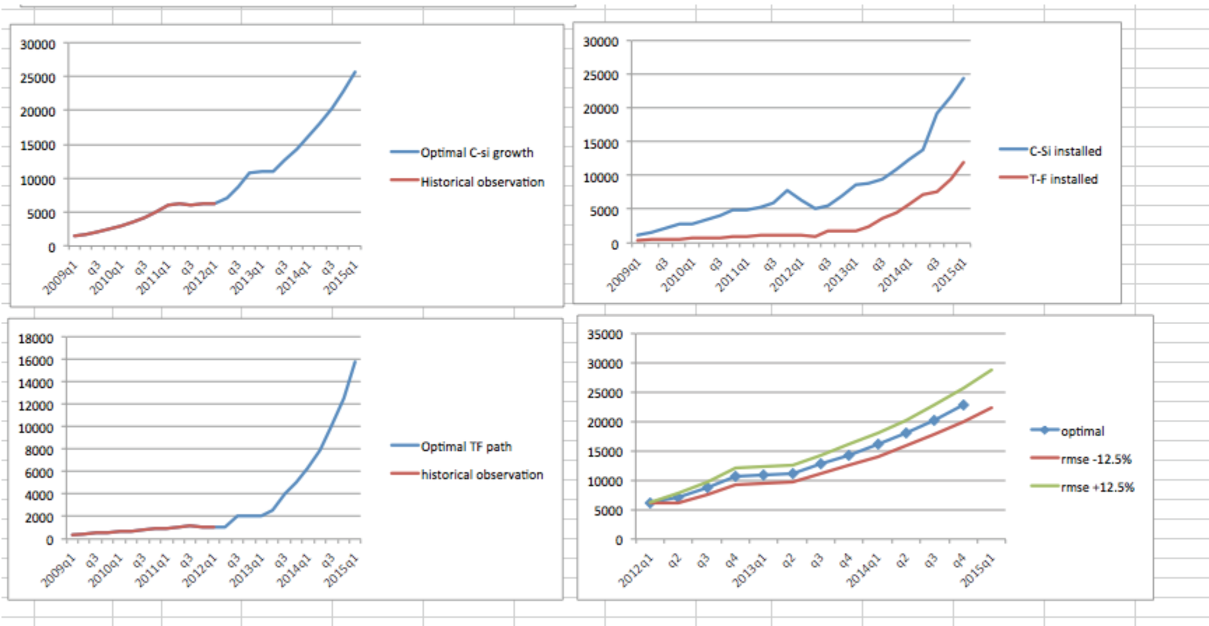

Figure29: Details scenari, and optimal paths

PV INPUT PER COUNTRY

table1:Worldwide production

				2009				2010				2011				2012
Source	Types	Caract	Unity	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13
PV Integrated Market Tracker 2010-2012	Polysilicon	demand	MT	13 765	15 263	17 618	19 573	21 298	25 556	31 956	37 468	43 126	44 449	43 575	38 102	38 957
		prod.cap	MT	23 942	26 764	31 673	35 872	40 316	43 950	48 943	54 581	62 920	66 605	74 667	81 240	76 654
		production	MT	20 131	22 285	25 229	28 524	31 492	34 597	39 896	45 857	50 535	52 569	55 418	54 684	51 672
		ASP	$/kg	103,63	84,99	80,16	72,23	66,25	65,77	67,46	67,32	66,83	64,92	58,05	33,29	31,00
	Wafer	demand	MW	1 768	2 005	2 644	3 009	3 516	4 219	4 975	5 707	6 625	6 759	6 386	6 478	6 879
		prod.cap	MW	2 753	2 965	3 257	3 448	3 913	4 647	5 725	6 810	7 916	8 857	9 515	9 004	9 392
		production	MW	2 102	2 355	2 749	3 082	3 391	4 109	5 171	6 132	7 081	7 323	7 202	6 319	6 482
		ASP	$/W	1,20	1,06	0,95	0,87	0,85	0,86	0,87	0,87	0,79	0,66	0,59	0,43	0,39
	Cells	demand	MW	1 517	1 790	2 250	2 608	3 516	4 219	4 975	5 707	6 625	6 759	6 386	6 478	6 879
		prod.cap	MW	2 726	2 896	3 117	3 287	3 913	4 647	5 725	6 810	7 916	8 857	9 515	9 004	9 392
		production	MW	1 715	1 945	2 565	2 919	3 391	4 109	5 171	6 132	7 081	7 323	7 202	6 319	6 482
		ASP	$/W	2,19	1,80	1,64	1,52	0,85	0,86	0,87	0,87	0,89	0,51	0,47	0,30	0,33
	C-Si Module	demand	MW	1 162	1 566	2 119	2 712	2 847	3 460	4 077	4 918	4 973	5 353	5 922	7 883	6 345
		prod.cap	MW	2 404	2 589	2 877	3 099	3 592	4 269	4 990	5 878	7 425	8 158	9 229	9 921	10 188
		production	MW	1 471	1 736	2 183	2 530	2 887	3 592	4 264	4 986	6 007	6 346	6 124	6 280	6 423
		ASP	$/W	2,94	2,64	2,42	2,30	2,18	2,07	2,01	1,98	1,74	1,44	1,26	1,13	1,04
	T-F Module	demand	MW	343	406	499	611	626	745	786	859	800	845	1 041	1 130	1 120
		prod.cap	MW	612	684	716	752	813	905	989	1 081	1 327	1 632	1 833	1 947	1 992
		production	MW	376	477	542	589	648	746	830	911	975	1 048	1 153	1 120	1 094
		ASP	$/W	2,10	2,10	1,79	1,65	1,59	1,58	1,54	1,52	1,33	1,12	0,93	0,85	0,81
	Modules	demand	MW	1 504,3	1 971,9	2 618,0	3 322,9	3 472,8	4 204,2	4 863,6	5 777,4	5 772,4	6 197,8	6 963,9	9 013,0	7 465
		prod.cap	MW	3 015,3	3 272,6	3 593,9	3 851,4	4 405,6	5 173,4	5 979,0	6 959,5	8 752,5	9 790,6	11061,44	11867,19	12 180
		production	MW	1 847,4	2 213,2	2 724,9	3 119,6	3 534,5	4 337,6	5 094,2	5 896,8	6 981,8	7 393,9	7 276,9	7 399,5	7 517
		ASP	$/W	2,5	2,4	2,1	2,0	1,9	1,8	1,8	1,8	1,5	1,3	1,1	1,0	0,93

Figure30: PV Input per country, Polysilicon, Wafers, Cells, Crystalline and Thin Film production, capacity of production, average selling price from 2009:q1 to 2012:q1

PV OUTPUT PER COUNTRY

PV Integrated Market Tracker 2010-2012

table3:Per sectors

		2009			2010			2011		
		Residential	Commercial	Ground	Residential	Commercial	Ground	Residential	Commercial	Ground
Belgium	installation	116,8	146,0	29,2	244	102	62	503	113	135
	revenues	666,38	640,78	112,63	1077,84	395,88	224,13	2118,56	417,20	465,95
	unity price	5,71	4,39	3,86	4,43	3,86	3,62	4,22	3,71	3,45
	ROI				9,32	9,82	11,88	7,56	8,21	8,99
Bulgary	installation	0,7	0,7	5,6	2	2	17	9	9	72
	revenues	4,00	3,49	25,06	11,00	9,00	65,00	35,58	33,00	244,00
	unity price	5,72	4,99	4,48	5,50	4,29	3,87	3,95	3,67	3,39
	ROI				0,47	9,04	11,63	10,33	9,93	10,58
France	installation	125,0	100,0	25,0	343	254	121	412	544	515
	revenues	1071,54	669,27	130,16	2703,16	1234,78	478,08	2201,85	2206,56	1659,65
	unity price	8,57	6,69	5,21	7,88	4,86	3,95	5,35	4,06	3,23
	ROI				8,20	13,74	11,75	<0	9,76	< 0
Germany	installation	1 599,0	1 484,0	723,0	2 617	3 240	1 551	3 100	2 500	1 904
	revenues	8216,09	6790,71	2979,77	10630,36	11333,23	5109,36	9507,83	6633,45	4224,81
	unity price	5,14	4,58	4,12	4,06	3,50	3,29	3,07	2,65	2,22
	ROI				10,01	7,76	6,21	9,39	3,99	4,77
Rep.techq	installation	20,0	20,0	357,0	74	74	1 341	10	5	5
	revenues	137,58	118,05	1823,70	357,12	292,16	4890,93	33,00	14,00	14,00
	unity price	6,88	5,90	5,11	4,79	3,92	3,65	3,30	2,80	2,80
	ROI				6,61	8,85	10,95	6,84	no incentives	no incentives
	installation	194,4	424,8	100,8	715	1 610	1 252	1 738	3 360	2 591

PV Integrated Market Tracker 2010-2012

table4:YoY

		2009	2010	2011
Belgium	installation	292,00	408,00	750,00
	revenues	1 419,79	1 697,86	3 001,72
	unity price	4,86	4,16	4,00
	PV.elec.prod	300,00	400,00	1 150,00
	sum.elec.cor	86 000,00	90 000,00	93 000,00
Bulgary	installation	7,00	20,90	90,00
	revenues	32,55	85,00	312,58
	unity price	4,65	4,07	3,47
	PV.elec.prod	100,00	120,00	180,00
	sum.elec.cor	29 000,00	30 000,00	28 000,00
France	installation	250,00	718,00	1 470,00
	revenues	1 870,97	4 416,02	6 068,07
	unity price	7,48	6,15	4,13
	PV.elec.prod	560,00	1 030,00	2 450,00
	sum.elec.cor	480 000,00	518 000,00	468 000,00
Germany	installation	3 806,00	7 408,28	7 503,28
	revenues	17 986,57	27 072,96	20 366,09
	unity price	4,73	3,65	2,71
	PV.elec.prod	8 230,00	11 570,00	18 280,00
	sum.elec.cor	549 000,00	512 000,00	548 000,00
Rep.tcheq	installation	397,00	1 489,78	20,00
	revenues	2 079,33	5 540,20	61,00
	unity price	5,24	3,72	3,05
	PV.elec.prod	400,00	1 040,00	1 690,00
	sum.elec.cor	62 000,00	70 000,00	64 000,00
	installation	720,00	3 577,00	7 689,00

table5:Solar yield (I	
Belgium	
Bulgaria	
Czech Republic	
China & USA	
France	
Greece	
Italy	
Japan	
United Kingdom	
Germany	

legends	
installation	MW
revenues	M$
ROI	%
PV.elec.prod	MW
elect.consom	MW

Figure31: PV output per country. It includes European countries, Japan, USA, China, where PV is the most deployed.

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